These difficulties that AOA systems face are balanced by strong advantages; most importantly low cost of equipment per cell site, and low system set-up costs.

The AOA system by AccuCom at a prototype stage was trialed by GTE in San Diego. Although the details are proprietary, location performance that approaches the FCC Phase II requirement was demonstrated under limited scenarios. Pre-production system hardware is slated for a trial later in 1st Q'97.

4.3 Time Difference of Arrival (TDOA) Technology

Time difference of arrival is a well known technique used for determining the locations of mobile devices. TDOA has been used for radar systems in the past and for GPS today. This approach has been pursued by the Associated Group Inc. (AGI), whose system TruePosition is used in this trial, and is described in more detail later. US West/New Vector group and Lockheed Sanders are also known to have invested efforts in this technology but little is publicly known of their respective programs.

The idea of this technique is to use pulses normally transmitted by the mobile as the source of information on the vehicle location. Such pulses are routinely transmitted over the reverse control channel. The burden of receiving these pulses and time-stamping them is handed to specially equipped LDT cell sites, which must maintain a common high precision time frame. The analysis of the received pulses TOA is delegated to a special LDT control center (one or two of which are needed for a metropolitan area), which extracts the TDOA information by comparing the TOA per each *pair* of cell sites, and later uses the TDOA data to calculate the emitter's location.

The two main problems with the TDOA solutions are multipath effects, and keeping a tight time synchronization between the LDT-equipped cell sites. Multipath effects are expected to introduce significant errors in densely built areas. Multiple signal returns are created, reflected from nearby obstacles, that are almost indistinguishable from the direct path return. The ambiguities that the multipath effects create can probably be resolved at the expense of costly antennas and receivers, and longer processing times. Bringing up time-synchronization between the LDT-equipped cell sites and maintaining it is an expense unique to the TDOA technology. To maintain high accuracy, Rubidium clocks are used. The commercial accuracy level of these is 10^{-11}, which translates to a slip in time of 35.4 ns/hr, or about 35.4 feet/hr error. Calibration pulses transmitted frequently by an independent site could be used to reset the timing and mitigate this problem.

One advantage of a TDOA system is that simple inexpensive antennas are needed at the cell sites. The cellular system antennas could be used if their configurations (height, beamwidth, tilt, etc.) are consistent with the coverage needs of the TDOA system. Another advantage is, in principle, a lower sensitivity to multipath compared to AOA, although this tends to depend on the specifics of the system at hand.

In the GSM world, Ericsson, a leading infrastructure equipment manufacturer, has also been pursuing this approach but little is known about its current status. In GSM, despite the fact that time is maintained at the base stations, and throughout the system within certain limits, the problem remains challenging. (GSM uses Time Division Multiple Access, TDMA, to support multiple users simultaneously). This difficulty is still present in spite of the higher composite channel rates of GSM of 270 kbps, when compared to the 10 kbps digital signaling information in AMPS on the reverse control channel. (The higher the bandwidth and the shorter the bit duration, the more accurate the timing obtained over a certain fixed observation period.) The difficulty arises primarily from the tight timing requirements of TDOA-based location, which are different from the requirements in the GSM system specifications implemented thus far.

In the TDMA standard of the U.S. (IS-136) the bit rates are significantly lower than in GSM, and the system timing specifications are considerably more lax. Hence the problem becomes even more challenging. However, since IS-136 is often used as a complement to AMPS, the system for analog cellular could probably be used.

As for CDMA, since it uses spread spectrum, the same type of waveform used by GPS, one could intuitively conclude that a TDOA system would be a natural choice for CDMA. The biggest challenge in CDMA is the very tight power control exerted on the mobile unit which results in the purported capacity increases. This power control makes it virtually impossible "to hear" a mobile user at neighboring base stations when it is close to one. This typically happens within 1/3 of the cell radius, which is a significant region. To overcome this daunting difficulty, a hybrid scheme that can rely on one site only part of the time appears to be necessary. This can be accomplished either by TDOA with AOA, or AOA with ranging (TOA). Wireless network-based systems for CDMA are still at the concept phase.

4.4 Accuracy Versus Independent Infrastructure Systems

Although independent infrastructure location systems are not well suited to the wireless E-911 application, a cursory examination of some of their key features provides significant insights into the challenges and limitations of network-based systems.

As alluded to earlier, independent infrastructure systems have been designed and built specifically to provide accurate locations. Some of their salient characteristics include: broadband signals (typically spread spectrum), known signals (typically pseudo-noise [PN] codes), good geometry with overlapping coverage from multiple elevated sites (satellites or high towers), and accurate timing integral to the system.

GPS uses an array of 24 satellites (21 primary satellites and 3 spares) in six orbital planes at an altitude of 10,900 nautical miles above earth. The GPS satellites continuously transmit precisely timed signals which include information that enables GPS users to accurately determine the satellite's position in orbit. Since the signals travel at the speed of light, the amount of time that elapses from transmission to reception is easily converted by the receiver to the range to the corresponding satellite. Range measurements to four or more satellites are generally needed for a receiver to compute location, but three satellites are sufficient if the altitude of the receiver above sea is not needed. For security reasons, the GPS accuracy is intentionally degraded by the U.S. government to 100 meters (95% probability). Average accuracy is quoted as 20 meters.

Differential GPS, also known as Local Area DGPS, is a technique that yields an improved GPS accuracy. A special GPS receiver is placed at a known (surveyed) location near the GPS user location. The offset between the known position of the special receiver to its computed position is broadcast to all nearby GPS users. Accuracy of DGPS is quoted to be on the order of 1 meter.

Because of the length of the path to the GPS satellites, the signals are weak and not adequate to penetrate buildings and provide location determination indoors. Some entrepreneurial efforts have been addressing combining GPS receivers with two way wireless services to extend coverage to where it does not exist today.

Terrestrial-based systems also exist that provide accurate location determination. Teletrac is one such system; its key target applications are commercial fleet management and stolen vehicle recovery. Again, its high towers transmit precisely timed broadband signals which are received by users equipped with the Teletrac transceivers. Several towers (a few tens) are required per metropolitan area, but significantly less than the hundreds of cell sites required today to provide adequate cellular coverage to a metropolitan area. Quoted accuracy is better than 30 m 90% of the time.

The Teletrac system is designed to achieve its accuracy for its target applications. In the stolen vehicle case the antenna is concealed inside the car. Hence performance accuracy is for outdoor reception and for cases where there is some penetration loss. Accordingly, some indoor operation is possible within this performance envelop. More extensive and guaranteed high indoor accuracy would require a denser deployment. The Teletrac system has been fully operational in 6 metropolitan areas and is currently being expanded in 19 others.

Interestingly, most of the technical features outlined above for independent infrastructure LDT's seem NOT to be satisfied in wireless network-based systems. This should not be taken against such systems, but only as a realization of the fact that the wireless networks were built for a completely different purpose, namely, completion of many voice calls. Often, the requirements of a high capacity wireless voice system are in conflict with those of a good location system.

In today's wireless networks, coverage of each cell site is curtailed to prevent interference to other sites where the frequency is reused to meet system capacity needs. This cell coverage limiting is done through lower antennas, down-tilting of those antennas, reduced transmit power, and tight mobile unit power control. In essence, the objective of the wireless network is to have the transmission to and from the user heard well at two locations only: at that mobile, and at its serving base station. The requirement of a good locating system, on the other hand, calls for redundant solutions from as many equipped cell sites as possible. The more a mobile unit's transmission can be heard at multiple sites the better the performance. Hence, high antennas and high transmitted powers are generally advantageous. These would obviously be in conflict with the needs of a busy, urban wireless voice system.

Thus, one should not expect a well designed wireless network-based LDT to perform as accurately as an infrastructure system built specifically for that purpose. The physics of the problem simply preclude that. The more the network based systems rely on the network's infrastructure and signals (which achieves reduction in location system cost) the less likely the performance will be near that of independent infrastructure systems. What can happen is that an LDT may elect to use, for example, separate higher antennas to enhance performance, or sites that are not co-located with cell sites to mitigate power control effects — basically both are features of an independent location infrastructure— both would achieve a measure of improved performance but at a substantial incremental cost.

Because wireless network-based LDT's leverage cellular installations to ensure economic viability, they are somewhat tied to operating with low antennas, surrounded on many occasions by local clutter. This kind of setting creates a limitation on accuracy caused by multi-path and by the inability of getting a good signal from a mobile transmitter that is closer to another cell site. This latter problem is exacerbated by power control if the LDT tracks the reverse voice channel. On the other hand, if the LDT tracks the reverse control channel it is typically not affected by power control (unlike the reverse voice channel, the reverse control channel is not power controlled.) However, the short length of the single control channel transmission burst (roughly 100 ms in AMPS) leaves little room for error, unfortunately in an environment that has various sources of error, for example caused by reflections and diffractions. These considerations make the 125 m accuracy requirement a challenging goal, particularly when difficult environments are considered, such as hills, canyons, high rises with reflective glass, and so on. The difficulty of the accuracy requirement is mitigated and made more feasible by the 67% of the time requirement. That number seems arbitrary, but reasonable nevertheless. More demanding requirements, such as 40 feet, are simply economically unfeasible for E-911 purposes in the foreseeable future.

5. Selection of AGI's Technology for Trial In Houston

The original intent of the WIP team was to bring to the Houston test area a number of prominent LDT's for comparative evaluation. This is in addition to the WIP's primary objective of demonstrating successful integration of the wireless (voice network and LDT) and wireline components of an E-911 system with sophisticated capabilities, such as accurate call taker map displays. A letter to invite prospective LDT vendors to participate was drafted and disseminated in early 1996. Most LDT vendors have been developing their systems in various parts of the US.

Because wireless network-based systems are intimately tied to wireless networks, the different vendors have been developing, testing, and field trialing their equipment in different forms of alliances with wireless carriers. For example AGI has tried its TruePosition system in Rochester, NY; Philadelphia, PA; Baltimore, MD; and most recently Houston, TX. On January 22, 1997, AGI began the 50-mile New Jersey Turnpike trial. Other location technology vendors are also active. AccuCom Wireless Services has been trialing its AOA system in San Diego with GTE Mobilnet. E-Systems/Raytheon has been trialing a system in the Washington, DC, area under the CAPITAL Project. Motorola has been trialing a system of their own which uses a combination of angle and time of arrival techniques, and is claimed to target digital cellular standards (such as CDMA) in addition to the present analog standard (AMPS).

The creation of a test deployment over a wireless network takes considerable effort. It requires developing a fairly good understanding of the voice network at hand and its operational environment. It also requires the selection of a number of cell sites to be equipped with LDT hardware, and once this selection is done integrating the equipment with a control center via communication links. All steps require interim testing, verification, and iteration. This is obviously a time consuming and costly process that stresses the scarce resources of both the location technology developer and the wireless carrier involved.

Unfortunately, most location technology developers found it unfeasible to move their test deployment to Houston, or to duplicate it there. Many of them were also concerned about the public display of their systems and their performance, and preferred quieter development arenas. The resource issues also affected some of the wireless carriers. GTE Mobilnet decided to not fully participate in the Houston WIP trial since it was already involved in a location trial in San Diego. Instead, it relied on GTE Telops' and GTE Laboratories' participation in the WIP trial to maintain GTE's presence in this critically important E-911 forum..

In spite of these resource challenges, AGI stepped forward and participated in the Houston Trial with the TruePosition system. However, AGI had to cannibalize the test system it was setting up for the Philadelphia trial for that purposes. Also the trial in Houston was limited to the purpose of demonstrating proper routing to the PSAP's, rather than of the location accuracy performance of the system. This is understandable at this stage, since an early prototype test deployment requires a significant degree of optimization to function at a level that is acceptable for public display.

From GTE's perspective, as telecommunications leader and a major wireless carrier, it is not yet committed to any LDT, and would like to see as many of them as possible developed, trialed, optimized, and proven over the five year period for the implementation of the Phase II E-911 requirement. GTE Labs therefore plays an active role in monitoring and assessing LDT's.

6. Salient Features of the TruePosition System

A more detailed description of the TruePosition system is provided elsewhere in this report. Here only the salient features pertaining to the locating mechanism, system architecture, and connectivity are discussed broadly. The specifics of the test deployment used in the Houston trial are outlined in the next section.

The TruePosition system uses TDOA to determine the positions of wireless callers. The system operates on the pulses sent by the mobile unit on the cellular reverse control channel, the RCC, at call setup or at the mobile unit's registration with the wireless network.

The location system consists of a so-called Signal Collection System (SCS) residing at each equipped cellular base station (although it does not necessarily have to be deployed there). Each SCS is basically a set of digital receivers, one for each receive antenna used per cell sector. To maintain an accurate common time frame, a high precision rubidium clock is needed at each receiver. The commercial accuracy level of these is 10^{-11}, which translates to a slip in time of 35.4 ns/hr, or about 35.4 feet/hr error. Another 100 ms pulse is transmitted by an independent fixed calibration site to maintain tight synchronization between the SCS sites, thus keeping the error due to synchronization to about half a foot.

The baseline configuration of the SCS calls for diversity reception wherein two receive antennas are deployed per sector. These antennas are either the cellular network's antennas or separate antennas if the location coverage requirements necessitates. Diversity reception is intended to improve performance and mitigate to some extent multipath; it is routinely used on the reverse channels of cellular systems. The results of diversity reception with the TruePosition location system has reportedly been inconsistent, underscoring some inherent differences between the location determination and voice communication problems.

The SCS's are each connected to a "control site" via a concentrator by means of DS0 lines. The number of DS0 lines needed per SCS depends on the number of receivers in it, which in turn depends on the specific traffic to be handled at that cell. One DS0 may suffice but up to 6 can be used.

The SCS receivers sample the RCC transmissions. The MIN, ESN, and called number are sent back to a subsystem at the control site called the TDOA Location Processor (TLP), as shown schematically in Figure 6.1. The full samples of the RCC are sent back only for those calls that are determined by the location processor to be requiring location. This reduces the required communication between the SCS's and the location processor.

The TLP contains all the algorithms necessary for computing location, and is also responsible for identifying the calls to be located based on a number of criteria. The TLP would typically be located at a wireless switch (MTSO or MSC). The TLP has an optional link to the switch, which would support a possible expansion to process the reverse voice channel by means of additional digital receivers at the SCS. In that case, voice channel parameters (e.g., upon handoff) are extracted from the switch. In its normal configuration the TruePosition system connects directly to the E-911 PSAP interface, rather than through the switch.

Another TruePosition subsystem called the Application Processor (AP) controls the TruePosition network, its interfaces and application related functions. The AP is a high performance database software system with a client server architecture.

The TruePosition system requires the reception of the mobile's RCC at least at four equipped sites. The algorithm, implemented at the location processor, cross-correlates the samples derived from the different cell sites, and basically takes the difference of the times of arrival (TOA's) at pairs of sites to create three contours (hyperbolas). The mobile is located in the region where these contours intersect.

Location performance is a function of many factors: Multipath, time bandwidth product of the signals detected and processed, instrumentation accuracy (e.g., clocks), number of receiving locations, antenna heights, use of diversity, antenna gains, and geometry (geometric dilution of precision or GDOP). The actual accuracy is a very complicated function of the above factors, which tend to vary from place to place in a given cellular environment. Thus performance can only be ascertained through extensive field measurements.

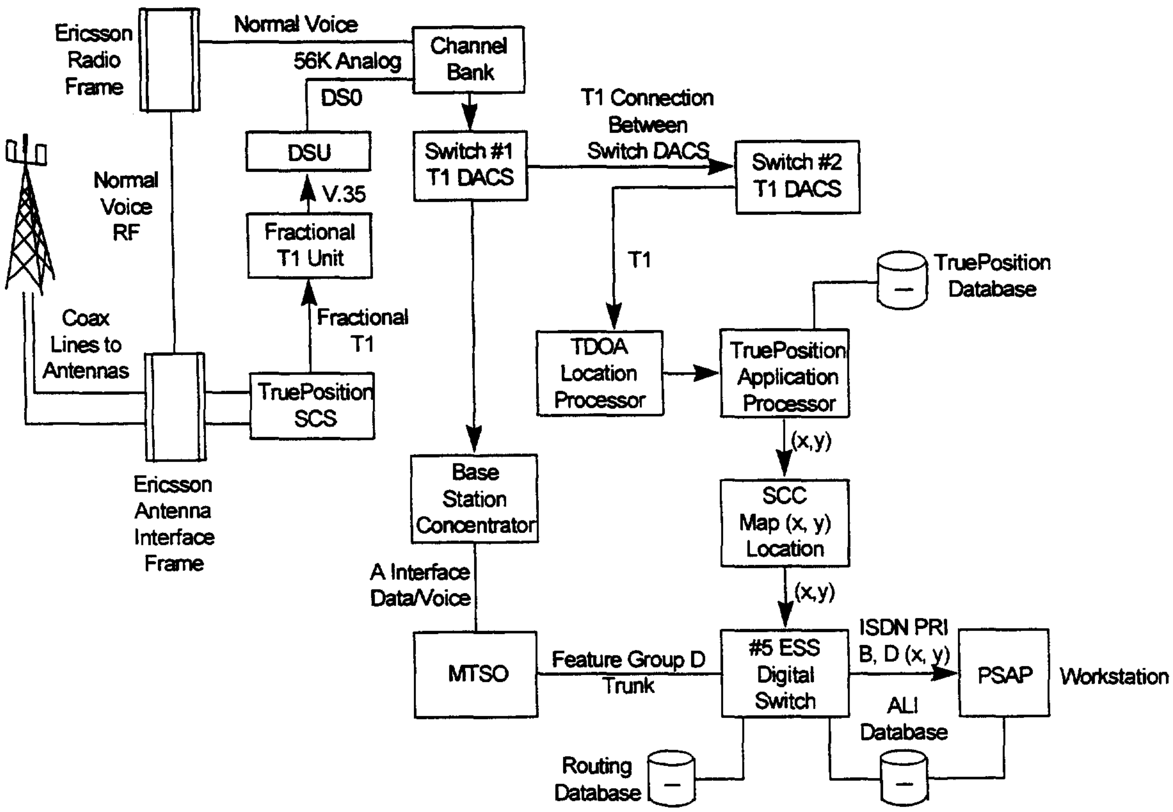


Figure 6.1 Architecture of the TruePosition System

Early calculations made by AGI have predicted that at each receiver end (i.e., at the equipped base stations) a signal to noise ratio ≥ 10 dB must be maintained in order to achieve a desired accuracy of about 500feet. While this requirement may seem reasonably easy to achieve in certain benign environments with dense deployments, AGI has acknowledged that under multipath conditions, "much higher" signal-to-noise ratios would be needed. Hence, actual system performance would have to be validated in various field deployments.

Since the TruePosition system uses only the short data burst on the RCC at call setup or registration, the delay in obtaining the position fix is generally small. Typical system processing delay is a minimum of 5 seconds from the moment a user presses the "SEND" button, during this time the location is determined so the routing can be established.

7. Trial Area

The field trial was located in the Houston area about 14 Km (8.7 mi) west of the down town center, the size of the coverage area was approximately 36 square Km (13.9 square mi), its geography was perfectly flat and with no water bodies or natural boundaries. The area was mostly residential. Most houses and buildings were one or two stories high, except a few which were four to ten stories high. Some highway bridges existed in the northwestern part of the area. The trees around the houses were generally 10 to 15 m high. In some areas the woods were dense. Overall, the area represents a fairly benign cellular propagation environment. Hence, the propagation affecting the accuracy of the location determination was minimized, in turn assisting in the routing of calls to the correct PSAP.

7.1 Area Boundaries and Cellular/TruePosition Deployment

The trial was conducted in an area marked by the boundaries shown in Figure 7.1. The boundaries basically join 6 Houston Cellular cell sites equipped with the TruePosition hardware. The northern boundary of that area runs north of I-10 by about 1.1 Km (.68 mi), just north of Westview Street between Campbell Street and the eastern end of Church Lane (Church Lane cell site). At the eastern side it runs between the Westview-Campbell intersection (Spring Valley cell site) and the San Felipe-Voss intersection (San Felipe cell site). From this it runs south west just to the south of the Westheimer-Gessner intersection (Tanglewilde cell site). It then extends to the west of I-8 by a little more than a block and south of Westheimer by about 170 m (560 feet) (Westheimer cell site). From there it runs north west just to the west of Sandy Spring-Wilcrest (Hayes cell site), and then it extends north east back to Church Lane.

Inside this boundary there are two more equipped cell sites, both are located about one large city block south of I-10, the first near the Bunker Hill-Barryknoll intersection and the second further west near Town and Country Village (Memorial). Thus the total number of equipped cell sites is 8. Among the 8 sites, the six perimeter cells had 10 sectors that were pointed towards the interior of the test area and were equipped with the TruePosition SCS hardware. Additionally, the two interior cells each had three equipped sectors as shown in Table 7.1. Thus the total number of equipped sectors was 16. This deployment translates into a density of about 4.5 square Km/equipped site (1.74 square mi/equipped site) and 2.3 square Km/equipped cell sector (0.9 square mi/equipped cell sector). Some key details on the equipped sites are provided in Table 7.1.

Figure 7.1. TruePosition Deployment and Test Area Boundaries

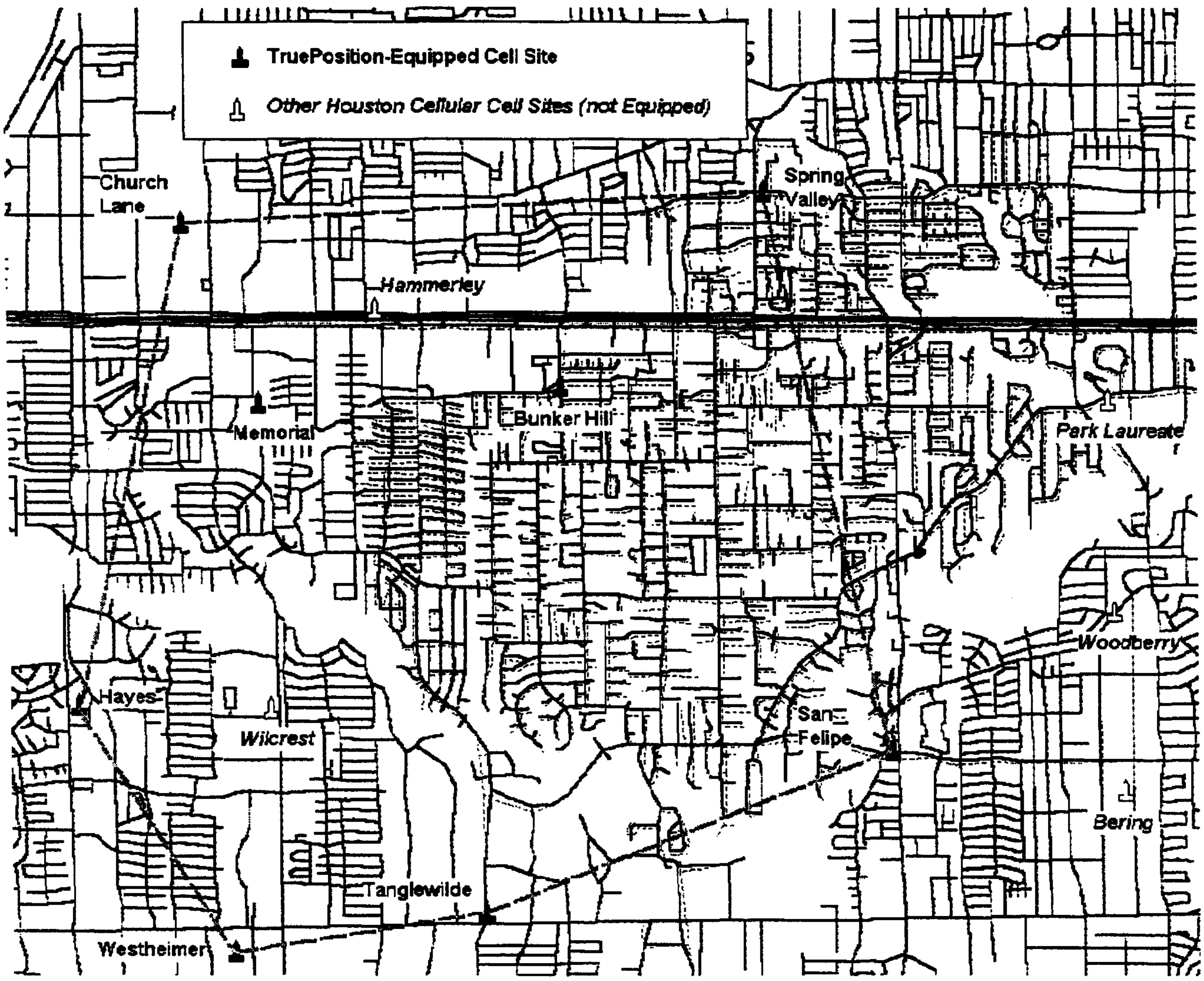
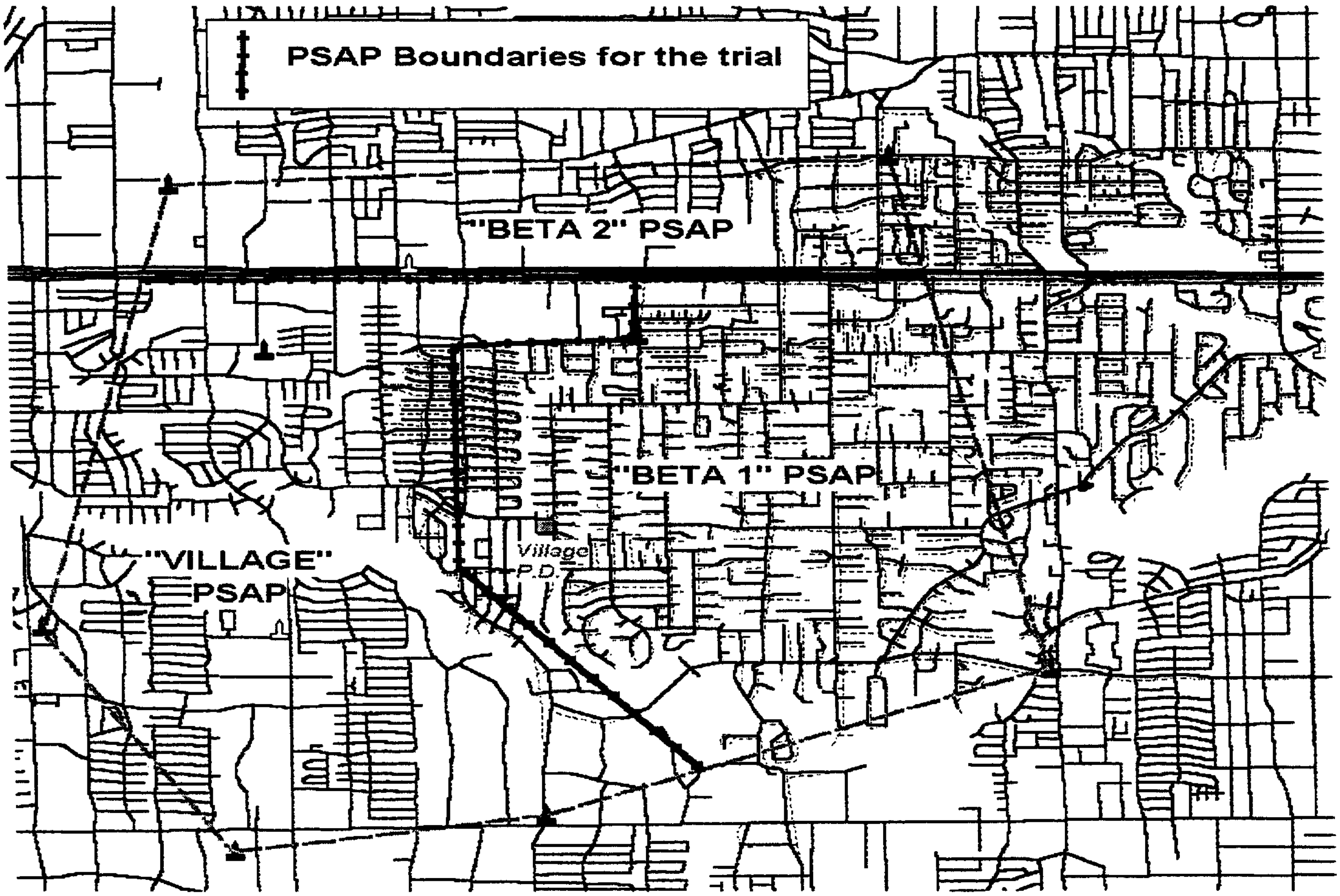


Figure 7.2. PSAP Boundaries within Test Area for the Trial



Houston Cellular has other cell sites in and around the area that were not equipped for the purposes of the trial. For example those called Park Laureate, Hemmerley, Bering and Wilcrest, which are also shown in Figure 7.1.

Among the equipped cells, the antenna at the San Felipe and Tanglewilde sites were installed atop 10-story buildings. At the remaining sites, monopoles of 23-35 m (75-115 feet) in height were used as specified in the table.

Table 7.1. TruePosition's Deployment on Houston Cellular's Infrastructure

Cell Name	Latitude	Longitude	Height (Meters)	# of Receivers	Equipped Sectors	Azimuth
San Felipe	29.75056	95.50167	19.2	2	Gamma	270
Spring Valley	29.79444	95.51306	23.0	2	Gamma	240
Church Lane	29.79194	95.56585	23.0	2	Beta	120
Hayes	29.75419	95.57556	25.0	2	Alpha, Beta	60,120
Westheimer	29.73502	95.56166	23.0	4	Alpha, Beta	0, 120
Tanglewilde	29.73808	95.53891	22.0	6	Alpha, Beta, Gamma	0, 120, 240
Memorial	29.77782	95.55918	30.0	6	Alpha, Beta, Gamma	0, 120, 240
Bunker Hill	29.77918	95.53168	25.0	6	Alpha, Beta, Gamma	0, 120, 240

One of the major objectives of the trial was to verify correct routing of wireless 911 calls to the proper PSAP. For this purpose the test area was divided into three parts, each handled by a separate answering station representing a different PSAP. As depicted in Figure 7.2, the area north of I-10 was assigned to the "Beta 2" answering station or PSAP. The area south of I-10 was divided by a line running southward along Bunker Hill, westward along Barryknoll to the Gessner intersection, and from there southeast to near Shady Lane. The area to the east of this partition was assigned to the "Beta 1" answering station, while the western part was assigned to the Village P.D. station (PSAP). It is worth noting that the Village PSAP was physically located inside the Village P.D. which was within the Beta 1 PSAP coverage area as shown in Figure 7.2. The Beta 1 and Beta 2 emergency call reception equipment resided in a location several miles to the east of the test area, at 602 Sawyer Street, Houston.

7.2 Configuration of Test System

As described earlier and shown in Figure 6.1, AGI's TruePosition system used in this field trial consisted of three main components: the Signal Collection System (SCS), the TDOA Location Processor (TLP), and the Application Processor (AP). The last two were physically located at AGI's main office in Philadelphia. The SCS was basically a receiver that receives the RCC transmissions occurring on all wireless phones using a wide band digital receiver. The SCS was installed at the eight cell sites identified above in Figure 7.1. The SCS hardware is connected to the antenna through the existing coax line running from the antenna to the base station.

For the purposes of the trial 211 calls were made to emulate 911 calls. When a 211 call was sent by a mobile unit, the SCS's at the listening cell sites detected the associated RCC transmissions, and sent the information over DS0 lines (one per receiver) to a concentrator housed at 602 Sawyer Street in Houston. The data was then relayed to the TLP in Philadelphia via a T1 line. Upon receiving the data, the TLP processed the information and estimated the callers longitudinal and latitudinal coordinates which were then sent to SCC's ALI database in Boulder, Colorado. Based on that, routing data was determined and an update to the routing database at SCC was entered.

In the mean time, as the TLP processed the data, the 211 call was routed across the wireless and wireline networks to a tandem, which is in this case was a #5 ESS digital switch as shown in Figure 6.1. One of the functions of this switch has been to query the database, so when it received the 211 call it sent a query to the ALI and routing databases at SCC asking for the latest update of the database. Upon receiving the query's answer, the switch packaged the data with voice and sent it to the assigned answering point. There was no direct link or time synchronization between the TLP and the #5 ESS switch, and each one of them operated independently of the other.

8. Tests Performed

The principal objective of this trial from a location determination standpoint was to evaluate the performance of AGI's LDT network-based E-911 solution. In particular the proper routing of the wireless 911 calls to the appropriate PSAP.

Various system performance attributes related to the FCC E-911 requirements were observed and analyzed. They included:

- *Proper Routing*: To check for proper routing to the appropriate PSAP's. Calls were made throughout the test region with many calls near lines dividing the three different PSAP areas.

- *Accuracy*: The accuracy of location determination was only investigated for stationary callers. Calls were made near road intersections for accurate geographical reference. A map that was corrected by driving the roads with a DGPS-equipped vehicle was used to obtain the location to within 5-10 meters.

- *Repeatability*: Multiple calls were made from the same spot to check for the consistency and repeatability of location estimation and PSAP routing in the same environment.

- *Response time*: Time elapsed between sending the wireless call and the ringing tone at the PSAP; also the response time for the process of location estimation and communication to the ALI database and its update. Because of network switching constraints, at times the call was received at the PSAP before the ALI database had been updated with a location from TruePosition.

- *Reliability*: Observations of indications of performance and operational reliability and consistency over the test period which started by12/2/1996 and ended 12/20/1996.

All test calls used in the analysis found in this report were carried out by GTE Labs personnel. The exact call locations were recorded on log sheets along with time and environmental conditions.

9. Trial Results

For the most part, the trial was designed to confirm the proof of concept that the AGI system can be integrated into the wireless/wireline network and be interfaced with the PSAP's. The trial area represented a typical mixed use urban/suburban environment with buildings, houses, trees, and car traffic. As in a typical cellular environment, a direct Line of Sight (LOS) did not exist for most of the test calls. The cellular traffic was not heavy, since vast majority of the calls went through without encountering a fast busy signal. Some observations from the trial follow.

9.1 Call Setting

Calls to 211 (which emulated E-911 for the purposes of the trial) were made, almost entirely, from stationary locations. The Beta2 and Village P.D. PSAPs were connected with analog CAMA trunks, and a delay could be introduced in the voice call long enough for the location to be processed. The Beta1 PSAP used a PRI ISDN line and could not be delayed enough. In most cases, calls from Beta1 area were made twice, and some times more, to allow time for the TLP to update the ALI database and retrieve the correct query reply. This is because the #5 ESS switch sent its query to the ALI database and received an answer faster than the updating of the database with the call location information. With its present implementation, the #5 ESS switch could not be slowed down to allow for the retrieval of the proper location update from the ALI database. Some of this can be attributed to the fluctuation in the time taken by the TLP to update the ALI database. The answering workstation could also query the ALI database by using the command "Repeat ALI" which can be used at time intervals of at least 15 seconds.

9.2 Call Routing

The data showed that at the times when the system was in its best operational state, the number of calls routed correctly to the appropriate PSAP reached 75 percent. This is illustrated in Table 9.1, which shows multiple calls placed from the same location. This could be explained, in some cases, by the inaccuracy in location estimation or the failure of timely updating of the ALI database. Incorrect routing happened also when parts of the system were down, although these occasions were not considered in computing the above percentage.

Table 9.1 Sample of Calls Routed Illustrating Call Routing Statistics

Time (Dec. 12, 1996)	Actual Location	Correct PSAP	Receiving PSAP
11:00	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:02	Flintdale St. & Starwood St.	Beta-1	V.P.D.
11:05	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:07	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:10	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:14	Flintdale St. & Starwood St.	Beta-1	V.P.D.
11:17	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:20	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:24	Flintdale St. & Starwood St.	Beta-1	V.P.D.
11:26	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:30	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:32	Flintdale St. & Starwood St.	Beta-1	Beta-1
11:12	Campbell St. & Bace St.	Beta-2	V.P.D.
11:13	Campbell St. & Bace St.	Beta-2	Beta-2
11:14	Campbell St. & Bace St.	Beta-2	Beta-2
11:21	Campbell St. & Westview St.	Beta-2	Beta-2
11:27	Campbell St. & Old Katy RD.	Beta-2	Beta-2
11:38	Lumpkin St. & Old Katy RD.	Beta-2	Beta-2
11:40	Lumpkin St. & Old Katy RD.	Beta-2	V.P.D.
11:42	Lumpkin St. & Old Katy RD.	Beta-2	Beta-2

9.3 Response Time

Call response time, the elapsed time between sending the 211 call and the start of ringing at the PSAP, was found to range between 4 to 10 seconds 90 percent of the time, and 10 to 14 seconds for 10 percent of the time, this includes normal cellular call setup time. Note that not always the call was received by the PSAP with an up to date location fix.

Table 9.2. Sample Calls Illustrating Response Time

Time (Dec. 20, 1996)	Actual Location	Response Time (Sec)	ALI Updating Status
11:05	Campbell St. & Bace St.	12	No
11:12	Campbell St. & Bace St.	9	No
11:13	Campbell St. & Bace St.	10	Yes
11:14	Campbell St. & Bace St.	10	Yes
11:21	Campbell St. & Westview St.	11	Yes
11:27	Campbell St. & Old Katy RD.	9	Yes
11:38	Lumpkin RD. & Old Katy RD.	5	Yes
11:40	Lumpkin RD. & Old Katy RD.	5	No
11:42	Lumpkin RD. & Old Katy RD.	5	Yes
11:46	Lumpkin RD. & Larston RD.	6	No
11:50	Lumpkin RD. & Larston RD.	5	Yes
11:59	Conrad Sauer & Old Katy RD.	8	Yes
12:02	Conrad Sauer & Old Katy RD.	9	No
12:07	Gessner St. & Old Katy RD.	8	No
12:15	Pine Lake St. & Demaret St.	9	No
12:17	Pine Lake St. & Demaret St.	7	No
12:38	Taylorcrest St. & Blalock St.	9	Yes
12:49	Taylorcrest St. & Piney Point	10	Yes
12:52	Echo Lane & Gaylord St.	8	Yes

9.4 Map Display of Calls

The x and y coordinates of the emulated 911 call and the MIN of the caller were sent to the PSAP's either by analog line modem or ISDN. When they arrived, the Nortel Option 61 or Option 11 console equipment were used to drive a Mapinfo display with an arrow pointing to the caller's location. The display also generated a circle around the point whose circumference is estimated to be at the 95% probability level.

10. Conclusions

The WIP trial in Houston has succeeded in demonstrating the integration of the various wireless and wireline components required to provide a wireless E-911 capability. The trial has been successful in identifying and resolving many of the interface issues among the disparate subsystems that interact to enable E-911. These subsystems include the MTSO, tandem, ALI database, location detection hardware on cell sites, remotely located location processor, and PSAP call taker elements. The trial clearly showed that dynamic routing of the wireless 911 calls to the proper PSAP based on the ANI and the latitude/longitude location is possible today. It also showed the feasibility and utility of corrected, and therefore accurate, map databases.

The trial has been particularly successful in identifying the areas were further wireless/wireline integration, coordination, and standards setting is required. Most notably, although proper routing to the PSAP can be accomplished in the majority of the cases, the reliability with which this is achieved is still in need of improvement. Proper routing to the appropriate PSAP was accomplished in approximately 75% of the calls when the system was completely functional. This has pointed out to two areas that are still in need of continued effort.

One key area is the timing and synchronization of the various components. For example, because of the current implementation of the #5ESS switch and its ISDN link to the PSAP, it is not possible to insert a delay at that juncture to allow enough time for the location processor to determine the location fix, communicate it to the ALI database, and allow the latter to be updated with the location, and provide the response to the PSAP before the call is answered. Although this situation can be mitigated by the PSAP manually requesting an ALI update from the ALI database, it is not a desirable condition. Therefore, equipment and software modification approaches, such as delay means in trunks and switchs and the speed up of TruePosition methods, and their cost implication need to be identified to resolve this timing issue.

Another key area is in the location estimation. Due to the short time available for the location vendor and the tight schedules of the demonstration, it was not feasible to fully set-up and calibrate the TruePosition system to perform to its best potential in determining locations during the Houston trial. Location estimation inaccuracies thus contributed at times to the improper routing of calls to PSAP's.

The latest performance of the TruePosition system needs to be examined in the Philadelphia/NJ area where adequate time has been available to the vendor to ensure proper system set-up and calibration. Moreover, all location technology vendors need to be actively monitored to identify their system development status and technology maturity, as well as location determination performance. Although the FCC's Phase II requirement (location to within 125 m 67% of the time) is still more than four years away, the problem of location estimation using wireless network-based technologies, and their interface to the PSAP's to support E-911 is a complex and challenging problem. The WIP trial in Houston has paved the beginning of the trail but much tenacious work lies ahead.

Texas Wireless Integration Project

Project Plan Summaries

Phase I and Phase II

WIP Phase I Project Plan

WIP Project Plan Task List	Duration	Start	Finish	Prime
Select PSAP Test Sites with VISIT ENR	5d	10/1/95	10/6/95	GHC
Select Phase I Test Cell Tower	5d	11/3/95	11/10/95	GHC
Install T-1 between MSC and GHC Switch	10d	11/13/95	11/27/95	SBC
Obtain Base Map, Build ESN	10d	11/16/95	11/30/95	TC
Build Cell Site RF Coverage overlay maps	10d	11/16/95	11/30/95	TC
Design software for routing / map display	5d	12/4/95	12/11/95	NT
Conduct Team meeting	1d	12/13/95	12/14/95	NT
Finalize Contracts with Cellular Carrier	21d	12/21/95	1/18/96	GHC
Evaluate and demonstrate test system	22d	12/29/95	1/29/96	Team
Create documentation	15d	1/1/96	1/21/96	TC
Create SW for 10-digit number table	22d	1/1/96	1/30/96	NT
Install software to que coverage displays	12d	1/3/96	1/18/96	NT
Establish Test Number (X-1-1)	5d	1/9/96	1/15/96	GTE
Install Base Map and overlays	30d	1/18/96	2/29/96	NT
Create cell site / sector ID Tables	5d	1/11/96	1/18/96	NT
Create Final Report	15d	1/11/96	1/31/96	TC
Plan Video Production Layout	17d	2/8/96	3/1/96	TC,NT
Documentand modify Phase I diagram	10d	2/15/96	2/28/96	NT

WIP Phase II Project Plan PG1

WIP Project Plan Task List	Duration	Start	Finish	Prime
Obtain Houston Cellular Agreement	16d	6/21/96	7/12/96	GHC
Conduct Houston Cellular Meeting	1d	7/17/96	7/17/96	GHC
Define Operational Test Area	1d	7/17/96	7/17/96	AGI
Schedule site surveys	1d	7/17/96	7/17/96	AGI
Schedule Executive Team Meeting	1d	7/19/96	7/19/96	TC/NT
SCC 9-1-1 Interface & Facilities Design	15d	7/19/96	8/8/96	SCC
RF design/ plan traffic report from carrier	2d	7/25/96	7/26/96	AGI
Schedule Team Meeting	1d	8/9/96	8/9/96	TC/NT
Schedule Documentation Team Meeting	0.1d	8/12/96	8/12/96	TC/NT
Schedule Technical Team Meeting	1d	8/20/96	8/20/96	TC/NT
Revise Cell Site Locations per AGI Input	3d	8/22/96	8/26/96	HC
Establish Baseline Signaling	5d	8/25/96	8/30/96	AGI
Present RF Plan to Houston Cellular	1d	8/26/96	8/26/96	AGI
Define TLP and AP Location	1d	8/29/96	8/29/96	AGI
Formulate TP Facility Interconnect Plan	1d	8/30/96	9/1/96	AGI
Schedule Loc. Det. Analysis Meeting	1d	8/30/96	8/30/96	TC/NT
Formulate True Position RF Plan	5d	9/1/96	9/6/96	AGI
Draft SCS Install Method of Procedure	1d	9/2/96	9/2/96	AGI
Conduct Data Analysis Planning Session	1d	9/4/96	9/4/96	AGI
Schedule Training for SBC Technicians	1d	9/4/96	9/4/96	SBC
Create AP Interface Document	5d	9/4/96	9/10/96	AGI
Identify Cal- Transmitter Search Areas	1d	9/7/96	9/9/96	AGI
Develop Interface to Test PSAP's	1d	9/7/96	9/9/96	AGI
Secure Calibration Transmitter Sites	5d	9/8/96	9/13/96	AGI
Review Houston Cell - RF Plan Changes	5d	9/9/96	9/13/96	AGI
Design CPE PSAP Workstation Database	2d	9/10/96	9/11/96	TC
Review and Approve Design Plan	1d	9/11/96	9/11/96	AGI
Order Ancilliary LDT Equipment	1d	9/12/96	9/12/96	AGI
Define SCC System Loc'n Requirements	1d	9/12/96	9/12/96	SCC
Select SR/ALI System Location	1d	9/12/96	9/12/96	SCC
Create and Deliver GEO File for SR/ALI	1d	9/12/96	9/12/96	TC
Secure TLP and AP Location	5d	9/12/96	9/18/96	AGI
Prepare GEO File for use in SR/ALI & DCR	1d	9/13/96	9/13/96	SCC
Load GEO file Database to DCR	1d	9/14/96	9/16/96	SCC
Conduct Site Surveys	4d	9/16/96	9/19/96	AGI
Conduct Technical Meeting - St. Louis	1d	9/16/96	9/16/96	SBC
Receive Path and Noise characteristics	3d	9/16/96	9/18/96	AGI
Build final Task lists	1d	9/18/96	9/18/96	TC/NT

WIP Phase II Project Plan PG2

WIP Project Plan Task List	Duration	Start	Finish	Prime
Load SR/ALI & DCR Applications	1d	9/18/96	9/18/96	SCC
Impliment AP to SCC Facility	10d	9/19/96	10/2/96	AGI
Conduct SCS Lab Testing 1-8	2d	9/19/96	9/20/96	AGI
Receive Ancilliary LDT Equipment	10d	9/20/96	10/3/96	AGI
Evaluate Surveys, RF Traffic and SDP's	3d	9/23/96	9/25/96	AGI
Create True Position Configuration DB	2d	9/26/96	9/27/96	AGI
Prepare and Load Network Translations	5d	10/1/96	10/7/96	SBC
Activate 5eSS Network	51d	10/7/96	12/16/96	SBC
Prep Cal-Transmitter, TLP/ AP locations	5d	9/22/96	9/27/96	AGI
Prep Cells 1-8	16d	9/22/96	10/14/96	AGI
Facilities Installed, test interconnectivity	20d	10/7/96	11/1/96	AGI
Install Configuration Data base	1d	10/11/96	11/11/96	AGI
Install and test TLP & AP functions	10d	10/3/96	10/16/96	AGI
Test System Connectivity	1d	10/24/96	10/24/96	SCC
Establish Interface to Test PSAP & SR/ALI	1d	10/25/96	10/25/96	SCC
Establish Test Connect LDT to SR/ALI	4d	10/25/96	10/30/96	AGI
Install Trunks / Assign Test ESN's	5d	10/25/96	10/31/96	SBC
Install Cal-Trans, test AP/ SCC function	1d	10/28/96	10/28/96	AGI
Install and test facilities - SCS 1-8	4d	10/28/96	10/31/96	AGI
Conduct Full System Integration Testing	11d	10/31/96	11/14/96	AGI
Install ENR Workstations in Test PSAP's	1d	11/3/96	11/4/96	NT
Program WIP Software on ENR systems	7d	11/4/96	11/12/96	NT
Install SCC Tandem Computer Equipment	1d	11/4/96	11/4/96	SCC
SCC Tandem System Operational	31d	11/4/96	12/16/96	SCC
Schedule Team Meeting and Presentation	3d	11/6/96	11/8/96	TC/NT
Conduct System Drive and Locate Test	3d	11/14/96	11/18/96	AGI
Final Code changes on ENR Workstations	2d	11/14/96	11/15/96	NT
Evaluation of Drive Test Data	3d	11/18/96	11/20/96	AGI
Establish System Verification Meeting	1d	11/21/96	11/21/96	TC/NT
Fine Tune System	4d	11/21/96	11/26/96	AGI
True Position System on Line	15d	11/26/96	12/16/96	AGI
Perform Data collection and analysis	15d	11/26/96	12/16/96	GTE
Commence WIP System Trial Period	15d	11/26/96	12/16/96	Team
Perform System Test and Data Collection	11d	12/2/96	12/16/96	Team
Conduct System demo's and Presentation	3d	12/5/96	12/9/96	Team
Coordinate Video crew and Interviews	3d	12/5/96	12/9/96	NT
Conduct Analysis and Document project	35d	12/16/96	1/31/97	Team

FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C.

REPORT AND ORDER
AND
FURTHER NOTICE OF PROPOSED RULEMAKING

CC Docket No. 94-102

Revision of the Commission's Rules
To Ensure Compatibility with
Enhanced 911 Emergency Calling Systems